COASTAL MIXING

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LONG TERM GOALS

I seek to understand the mechanisms of turbulence and mixing in shallow water sufficiently well to be able to specify useful parameterizations for coastal circulation models.

OBJECTIVES

I believe that this goal can best be achieved through a combination of comprehensive measurement of the turbulent fluctuations, the larger scale flows that drive them and modelling. These turbulent flows are often complex and rapidly changing and can often be best measured using a combination of methods that measure a variety of spatial and temporal scales. My medium-term scientific objective is to make and analyze such measurements in cooperation with other investigators.

APPROACH

My technical approach is to use neutrally buoyant Lagrangian floats in combination with other instruments such as acoustic remote sensing, microstructure measurements and rapid CTD profiling. This instrumental suite can both map a given flow and determine its mixing rates.

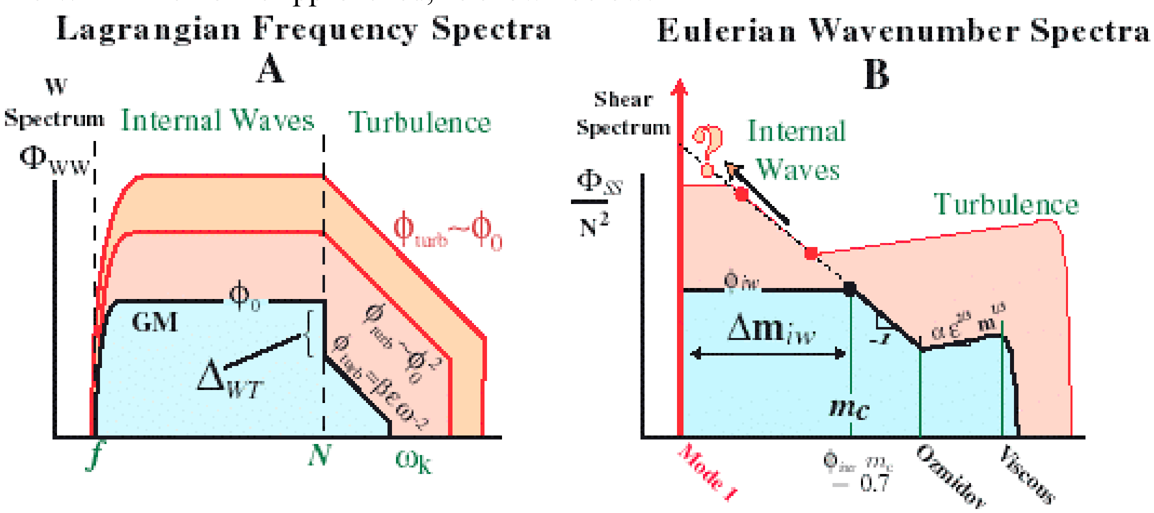
During the last decade, I have developed a new type of neutrally buoyant float (see picture on right) designed to be used in energetic turbulent flows such as those found in the top and bottom boundary layers of the ocean. A combination of accurate ballasting, compressibility matched to that of seawater and high drag is used to make these floats follow the motion of water parcels accurately. The floats measure their depth and are acoustically tracked in the horizontal and thus produce measurements of vertical and horizontal velocity. They measure the temperature and vertical vorticity (from spin rate) of the water surrounding them. We have made about 250 deployments of these floats, in a wide variety of turbulent coastal and open ocean environments. Analysis of this data has been conducted by the PI, by Ren-Chieh Lien and by students supported by NSF.

WORK COMPLETED

Over the last few years, we have exploited these unique measurements to study the properties, first, of homogeneous turbulence, and more recently of turbulence in the presence of stratification. Using data from the 1995 Knight Inlet experiment we have formulated a new set of hypothesis about stratified turbulence:

- Internal waves can be separated from turbulence via measurements of Lagrangian frequency. The waves have frequency less than N, the turbulence has frequencies greater than N.
- "Stratified Turbulence" has a large internal wave component. Thus much of the behavior of turbulence in a stratified fluid is determined by internal wave physics. Traditional stratified turbulence models do not recognize this.
- Mixing in a stratified fluid is controlled by internal wave/wave interactions at low energy and by shear or convective instabilities at high energies. A **Wave-Stratified Turbulence Transition** (W-T Transition) separates these two regimes. Stratified Turbulence models apply at energies above the transition energy while Wave-Wave Interaction models apply at energies below the transition.
- The transition spectral energy level is about 100 times the GM spectral level in the open ocean, but only 10 times the GM level on a typical shelf. Thus energetic regions of a continental shelf may lie above the transition, while quiet regions may lie below it.

These hypothesis are accompanied by predictions on the shape of Eulerian and Lagrangian spectra as the W-T transition is approached, as shown below.



At low energies (blue) the Lagrangian frequency spectrum of vertical velocity (A) extends from the Coriolus frequency *f* to the buoyancy frequency N, with little energy at higher frequency. The fluctuations are almost entirely in this internal wave band. As the energy increases, the turbulence velocity component, at frequencies higher than N, increases faster than the internal wave component. At the W-T Transition, the two curves merge at N and this spectral shape continues at energies above the transition. Approximately half the vertical velocity variance is now in turbulent motions with frequencies above N. Similarly, the Eulerian vertical wavenumber spectrum of shear (B), is white from the lowest mode out to a critical wavenumber m_c. As the energy increases, m_c decreases, approaching the lowest mode at the W-T transition, at which point the spectral shape must change.

These results have been reported in two papers submitted and accepted in the *Journal of Physical Oceanography*.

RESULTS

The form of these spectra implies a **new parameterization** for stratified turbulence relating the energy in the waves and the turbulent mixing rate. Above the W-T transition, flows $\varepsilon = w^2$ N; the rate of kinetic energy dissipation, □, is proportional to the mean vertical kinetic energy in the waves and the stratification N levels. Current second-order closure models use an equation of this form in their high-stratification limit, but with the total, rather than vertical kinetic energy.

Currently, two different types of models are used to model mixing in stratified flows:

Wave-Wave Interaction models assume that internal wave dynamics control the mixing processes, while *Stratified Turbulence* models assume that turbulence dynamics is controlling. My results imply that the first is appropriate for energies below the W-T transition, while the second should be used only at energies above the transition. Measurements of the spectra, in the ocean, can be used to assess which model type is most appropriate.

IMPACT/APPLICATIONS

Accurate models of internal waves and turbulence are crucial for modelling shallow water circulations. This work should allow improved models and, in particular, should allow a determination of whether the additional complexity of internal wave dynamics is needed to produce accurate simulations and predictions of mixing in complex flows.

TRANSITIONS

None

RELATED PROJECTS

These floats are close relatives of those used to study deep convection in the Labrador Sea funded by ONR 322OM. The same instruments have been used to study upper ocean mixing processes under NSF support. Mixing processes in these various environments are similar in many ways and we learn the most by comparing and contrasting them.

PUBLICATIONS

Lien, R.C. and E. A. D'Asaro, 1999, Lagrangian Measurements of Waves and Turbulence in Stratified Flows, in press, *J. Phys. Oceanogr.*

Lien, R.C. and E. A. D'Asaro, 1999, The wave-turbulence transition in stratified flows, in press, *J. Phys. Oceanogr.*